ENGIN STORAGE
TA
1
I6
no. 29
~~Physical & Applied Sci. Serials~~
Engineering
LIBRARY

VOL. 11 BULLETIN NO 3

IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

DECEMBER, 1912

Published Monthly by the Iowa State College of Agriculture and Mechanic Arts.
Entered as Second-class Matter October 26, 1905, at the Postoffice at
Ames, Iowa, under the Act of Congress, July 16, 1904.

BULLETIN NO. 29

Engineering Experiment Station

COSTS OF PRODUCING POWER IN IOWA WITH IOWA COALS

By

H. W. Wagner

AMES, IOWA

PURPOSE OF THE STATION

THE purpose of the Engineering Experiment Station is, first, to afford a service for the other industries of Iowa, similiar to that afforded by the Agricultural Experiment Station to the agricultural industries; second, to assist the urban population of the state in solving the technical problems of urban life; third, to solve the purely engineering problems of the agricultural population and industries of the state.

VOL. 11 BULLETIN NO. 3

IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

DECEMBER, 1912

Published Monthly by the Iowa State College of Agriculture and Mechanic Arts.
Entered as Second-class Matter October 26, 1905, at the Postoffice at
Ames, Iowa, under the Act of Congress, July 16, 1904.

BULLETIN NO. 29

Engineering Experiment Station

COSTS OF PRODUCING POWER IN IOWA WITH IOWA COALS

With a Comparison of Estimated Costs and
Costs from Actual Tests

By

H. W. Wagner, B. S. in E. E.
Assistant Engineer in Mechanical and Electrical Engineering

AMES, IOWA

ENGINEERING EXPERIMENT STATION

STATION COUNCIL

(Appointed by the State Board of Education)

RAYMOND A. PEARSON, LL. D.	President
ANSON MARSTON, C. E.	Director
LOUIS BEVIER SPINNEY, B. M. E.	Professor
SAMUEL WALKER BEYER, B. S., Ph. D.	Professor
WARREN H. MEEKER, M. E.	Professor
FRED ALAN FISH, M. E. in E. E.	Professor
JAY BROWNLEE DAVIDSON, B. S., M. E.	Professor

ENGINEERING EXPERIMENT STATION STAFF

RAYMOND A. PEARSON, LL. D.	President, Ex-Officio
ANSON MARSTON, C. E.	Director and Civil Engineer
LOUIS BEVIER SPINNEY, B. M. E.	Illuminating Engineer
SAMUEL WALKER BEYER, B. S., Ph D.	Mining Engineer
WARREN H. MEEKER, M. E.	Mechanical Engineer
FRED ALAN FISH, M. E. in E. E.	Electrical Engineer
JAY BROWNLEE DAVIDSON, B. S., M. E.	Agricultural Engineer
IRA A. WILLIAMS M. S., A. M.	Ceramist
JOHN EDWIN BRINDLEY, A. M., Ph. D.,	Engineering Economist
GEORGE A. GABRIEL, B. S. in Chem.	Industrial Chemist
CHARLES S. NICHOLS, B. C. E.	Assistant Director
A. O. ANDERSON, B. S. in Mn. E.	Assistant Engineer in Civil Engineering
HERBERT W. WAGNER, B. S. in E. E.	Assistant Engineer in Mechanical and Electrical Engineering
MILTON F. BEECHER, B. S. in Ceramics	Assistant Engineer in Ceramics
OTTO M. SMITH, B. S.	Assistant Chemist

VOL. 11 BULLETIN NO. 3

IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

DECEMBER, 1912

Published Monthly by the Iowa State College of Agriculture and Mechanic Arts.
Entered as Second-class Matter October 26, 1905, at the Postoffice at
Ames, Iowa, under the Act of Congress, July 16, 1904.

BULLETIN NO. 29

Engineering Experiment Station

COSTS OF PRODUCING POWER IN IOWA WITH IOWA COALS

With a Comparison of Estimated Costs and Costs from Actual Tests

By

H. W. Wagner, B. S. in E. E.
Assistant Engineer in Mechanical and Electrical Engineering

AMES, IOWA

ENGINEERING EXPERIMENT STATION

STATION COUNCIL

(Appointed by the State Board of Education)

RAYMOND A. PEARSON, LL. D.	President
ANSON MARSTON, C. E.	Director
LOUIS BEVIER SPINNEY, B. M. E.	Professor
SAMUEL WALKER BEYER, B. S., Ph. D.	Professor
WARREN H. MEEKER, M. E.	Professor
FRED ALAN FISH, M. E. in E. E.	Professor
JAY BROWNLEE DAVIDSON, B. S., M. E.	Professor

ENGINEERING EXPERIMENT STATION STAFF

RAYMOND A. PEARSON, LL. D.	President, Ex-Officio
ANSON MARSTON, C. E.	Director and Civil Engineer
LOUIS BEVIER SPINNEY, B. M. E.	Illuminating Engineer
SAMUEL WALKER BEYER, B. S., Ph D.	Mining Engineer
WARREN H. MEEKER, M. E.	Mechanical Engineer
FRED ALAN FISH, M. E. in E. E.	Electrical Engineer
JAY BROWNLEE DAVIDSON, B. S., M. E.	Agricultural Engineer
IRA A. WILLIAMS M. S., A. M.	Ceramist
JOHN EDWIN BRINDLEY, A. M., Ph. D.,	Engineering Economist
GEORGE A. GABRIEL, B. S. in Chem.	Industrial Chemist
CHARLES S. NICHOLS, B. C. E.	Assistant Director
A. O. ANDERSON, B. S. in Mn. E.	Assistant Engineer in Civil Engineering
HERBERT W. WAGNER, B. S. in E. E.	Assistant Engineer in Mechanical and Electrical Engineering
MILTON F. BEECHER, B. S. in Ceramics	Assistant Engineer in Ceramics
OTTO M. SMITH, B. S.	Assistant Chemist

The costs per unit of energy are slightly higher in the "actual" column than in the "estimated" column, but the average hours operated is only 75% of the time operated in the "estimated" column, which would naturally tend to make an even greater difference than that shown.

By a general comparison of all figures, the estimated costs seem to be higher than those figured from the actual tests in Iowa power plants: this is especially true as the load factor decreases. It is possible, however, that in the case of the tests certain operating expenses were omitted, such as management and bookkeeping.

Following is the relationship between some additional corresponding items on Tables I and III.

Table I: Steam consumption ranges from 13 to 30 lbs. per I. H. P. Hr.
Table III: Same ranges from 23 to 46.4.

“ I: Boiler pressure ranges from 100 to 150 pounds per square inch by gauge.
“ III: Same ranges from 57 to 125.

“ I: Efficiency of boiler and grate ranges from 55 to 60%.
“ III: Same ranges from 44 to 65%.

“ I: Water evaporated per pound moist coal ranges from 5.3 to 6.8 pounds.
“ III: Same ranges from 4.1 to 7.87.

“ I: Pounds coal per indicated H. P. Hr. ranges from 1.92 to 7.0.
“ III: Same ranges from 4.2 to 9.9.

“ I: Efficiency of conversion ranges from 49 to 81%.
“ III: Same ranges from 50 to 81%.

“ I: Cost of coal per million B. T. U. ranges from 11.1 to 13.6 cents.
“ III: Same ranges from 8.1 to 15.3 cents.

NOTE: In all the above comparisons, except efficiency of conversion, the figures are taken from Table I at 100% load factor, and from Table III at whatever load factor occurred in each case. Efficiency of conversion was taken from the extreme limits in both cases.

BULLETINS OF THE ENGINEERING EXPERIMENT STATION

*No. 1. The Iowa State College Sewage Disposal Plant Investigations.
*No. 2. Bacteriological Investigations of the Iowa State College Sewage.
*No. 3. Data of Iowa Sewage and Sewage Disposal.
*No. 4. Bacteriological Investigations of the Iowa State College Sewage Disposal Plant.
*No. 5. The Chemical Composition of the Sewage of the Iowa State College Sewage Disposal Plant.
*No. 6. Tests of Iowa Common Brick.
*No. 7. Sewage Disposal in Iowa.
*No. 8. Tests of Dry Press Brick Used in Iowa.
*No. 9. Notes on Steam Generation with Iowa Coal.
*No. 10. Dredging by the Hydraulic Method.
*No. 11. An investigation of Some Iowa Sewage Disposal Systems.
*Vol. II. No. 6. The Good Roads Problem in Iowa.
Vol. III. No. 1. Tests of Cement.
Vol. III. No. 2. State Railroad Taxation.
*Vol. III. No. 3. Steam Generation with Iowa Coals.
Vol. III. No. 4. Incandescent Lamp Testing.
*Vol. III. No. 5. Steam Pipe Covering Tests.
*Vol. III. No. 6. The Assessment of Drainage Districts.
Vol. IV. No. 1. Tests of Iowa Limes.
Vol. IV. No. 2. Holding Power of Nails in Single Shear.
Vol. IV. No. 3. Miracle Contest Papers for 1908.
Vol. IV. No. 4. Miracle Prize Papers for 1909.
Vol. IV. No. 5. Sanitary Examination of Water Supplies.
Vol. IV. No. 6. Sewage Disposal Plants for Private Houses.
Bulletin No. 25. Electric Power on the Farm.
Bulletin No. 26. The Production of Excessive Hydrogen Sulfid in Sewage Disposal Plants and Consequent Disintegration of the Concrete.
Bulletin No. 27. A study of Iowa Population as Related to Industrial Conditions.
Bulletin No. 28. History of Road Legislation in Iowa.
Bulletin No. 29. Costs of Producing Power in Iowa with Iowa Coals.

* Out of Print.

TABLE OF CONTENTS

PAGE
Introduction 4
Abbreviations Used on Tables and Curve Sheets 4
Definitions of Terms 5
Estimated Costs 5
Explanation of Items on Table I 12
Equipment of Plants on Table I 13
Calculations of Power Costs for Any Particular Plant 13
Curve Sheets 15
Power Plant Tests in Iowa 29
Explanation of Items on Table III 31
Equipment of Plants Tested 32
Comparison of Data on Tables I and III 33

INTRODUCTION

In working up figures on the generation of steam power with Iowa coals no special attempt has been made to point out the most economical methods of operation. The object has been mainly to analyze the details and to show what the power costs per brake horse power hour, delivered at the belt; and per kilowatt hour, delivered at the switch board, under the various common conditions of operation. All assumptions are made to represent as nearly as possible the average practice in Iowa.

The conditions assumed as variable are the load factor, the number of hours the plant operates during the year, and the cost of coal. Depending upon these, variations then occur in nearly all items of expense which go to make up the cost of the brake horse power hour and the kilowatt hour.

The types of equipments for the different sized plants on Table I are chosen to represent not so much the most economical types for each size of plant as the most practicable of those now in common use in the state. The type for each case considered is listed on page 13. Table III and attached notes give the sizes and types actually found operating in the state.

No attempt has been made to estimate or calculate the cost of electric power delivered to customers. That would involve the cost and upkeep of transmission lines, meters, etc. The initial cost as given includes nothing outside the power plant, proper.

The text and data in this bulletin have been worked out under the direction of W. H. Meeker, Mechanical Engineer, and F. A. Fish, Electrical Engineer, both of the Engineering Experiment Station.

ABBREVIATIONS USED ON TABLES AND CURVE SHEETS

Ave.	average
B. H. P.	brake horse power
B. T. U.	British thermal units
Da.	day
H. P.	horse power
Hr.	hour
I. H. P.	indicated horse power
K. W.	kilowatt
Lb.	pound
L. F.	load factor
Op.	operated
Sw' B'd.	switch board
Yr.	year
14% on I. Cost	14% on initial cost of plant

DEFINITION OF TERMS

Indicated horse power is the mechanical power developed in the engine cylinder by the steam working against the piston. It is measured from indicator cards taken from the engine cylinders.

Brake horse power is the actual mechanical power delivered by the fly wheel or pulley to the belt. It is measured by a prony brake or by an absorption dynamometer and is always less than the indicated horse power.

Kilowatt is a unit of electrical power equal to 1,000 watts.

One horse power equals 746 watts, or .746 kilowatts.

Conversely, one kilowatt equals 1.34 horse power.

Horse power hour and *kilowatt hour* are units of energy or work done by the respective power units in one hour's time.

Load factors are defined on pages 9 and 31.

ESTIMATED POWER COSTS WITH IOWA COALS

Table I gives the estimated costs of producing mechanical and electrical power in Iowa with Iowa coals. A thesis by W. M. Wilson[*] was used as a basis for these figures. This thesis was prepared from a large amount of data on costs and test runs collected by Mr. Wilson and presented by him for the professional degree of Mechanical Engineer at Sibley College of Cornell University, in 1904. It was published in the form of an abstract by Mr. Wilson in the January, 1907, number of "Power."

The figures worked out in this thesis were compared with cost data from other authorities and wherever a fair comparison could be made, were found to check fairly well. The general difference seemed to be that the other authorities gave somewhat lower costs.

The estimates in the original thesis were based upon the following conditions:

Fuel: Heating value of 14,000 B. T. U. per pound, moist coal. 60% of heat in fuel absorbed by water in boiler.

Condensing Water: 30 lb. water required to condense 1 lb. steam.

Cost, 1c per 10,000 lbs. condensing water.

---

[*] Mr. Wilson graduated from the Iowa State College in 1900. After a number of years on the instructing force, he became associate professor of Mechanical Engineering at the same institution in 1907, resigning in 1908.

Fixed Charges as a per cent of the Initial Cost of Plant.

Interest	5.0%
Depreciation	5.0%
Repairs	2.5%
Insurance	0.5%
Taxes.	1.0%
Total	14.0%

Methods of operation:

First: 10 hours x 310 days=3100 hrs. per yr.

Second: 24 hours x 365 days=8760 hrs. per yr.

Initial costs include duplicate feed pumps, one reserve engine and one reserve boiler in addition to those required for rated load.

"The cost of building for the horizontal engines and turbines was taken at $1.50 per square foot.——This is approximately the cost of a steel frame building having brick walls and a fireproof roof.——The price of land was taken at $0.50 per square foot."

Where condensers are not used it is assumed that feed water is taken from the heater at a temperature of 190 degrees: in the case of condensing engines it is taken at 160 degrees, and where economizers are used, it is fed into the boiler at 280 degrees.

"When the plant is used only ten hours per day, 310 days per year, coal is required for banking fires and getting up steam before the ten-hour period that the plant is in operation. An allowance of 5 pounds of coal per boiler horse power per day is allowed for this purpose."

The load factor was taken at 100%: i. e., the plants are assumed to run at full load during the time of operation.

In the original thesis from three to six types of engines were given for each size of plant. In the following but one type was chosen for each plant of a given rated capacity; a different type was chosen for each different size of station, while at the same time an effort was made to choose that one which was the most typical of those producing power most cheaply.

In order to fit Iowa conditions the following additions and modifications were made before arriving at the final figures:

Cost and Heating Value of Fuels:

First case: $3.00 per 2,000 lbs, delivered, for coal with a heat value of 11,000 B. T. U., per pound, moist.

Second case: $2.00 per 2,000 lbs., delivered, for coal with a heat value of 9,000 B. T. U., per pound, moist.

Boiler Efficiencies at 100% Load Factor:

60% of heat in 11,000 B. T. U. coal absorbed by water in boiler.

55% of heat in 9,000 B. T. U. coal absorbed by water in boiler.

With the above values the fuel cost of evaporating 1,000 pounds of water from and at 212 degrees with the $3.00 coal is 22c; with the $2.00 coal it is 19.6c.

Initial cost of boilers and settings is increased 20% because of the greater boiler and furnace areas required to get sufficient heat out of the lower grades of Iowa coals. This increase in cost of 20% is arrived at as follows:

The efficiency of boilers is assumed as 60% in the original calculations. Under Iowa conditions an average of 57½% is assumed for the two grades of coal.

60% ÷ 57½% = 104%, the ratio of efficiencies.

The heat value of coal in the original data is taken at 14,000 B. T. U. per pound. Under Iowa conditions the average of 9,000 and 11,000 is 10,000 B. T. U. per pound.

14,000 ÷ 10,000 = 140%, the ratio of heat value in the coal.

104% x 140% = 146%, the ratio of weights of coal required to supply sufficient steam. In other words, 46% more Iowa coal under Iowa conditions must be burned than is estimated in the original data.

Assuming, roughly, that half of this increase in coal consumed is taken care of by a fast fire, the capacity of boilers and grates must be increased by 23%. This would then make an increased cost of the boilers and settings of about 20%.

Mechanical Efficiencies of Engines at 100% Load Factor:

100 and 200 horse power reciprocating units	85.0%
600 horse power reciprocating units	87.5%
Turbines	90.0%

Per Centages of Expenses at Various Load Factors:

% Load Factor	100	75	50	25
% Coal req., recip. engines	100	87.5	75	62.5
% Coal req., turbines	100	85	70	57.5
% Condensing water	100	100	90	80
% Attendance	100	100	100	100
% Oil and waste	100	100	100	100

The above percentages represent the relative costs per rated indicated horse power of plant and not per horse power actually developed. For instance, the cost of coal for reciprocating engines per rated indicated horse power is taken as 100% when the plant is running at 100% load factor or at full rated capacity. At 75% load factor when the average load is only 75% of the rated capacity, the coal required per rated indicated horse power is 87.5% of that required at 100% load factor. In other words, the whole plant takes seven-eighths as much coal to develop 75% of the rated load as it takes to develop full load.

The term "load factor" as used above, is the ratio between the average load and the capacity of the plant when both terms of the ratio refer only to the time operated. The same kind of load factor is used throughout on all data and curve sheets showing estimated power costs.

The above paragraph leads to the fact that more coal is required per horse power hour at the lower load factors. This is true because of lower boiler and engine efficiencies when working at lower load factors or when the plant is under loaded. Oil and waste and attendance costs are assumed to be the same for the whole plant at all load factors. Reciprocating engines are assumed to take a greater percentage of coal at the low load factors than the turbines because their efficiency drops more rapidly. The above figures referring to the various expenses at different load factors were derived from a study of the tests and data from different authorities.

The figures given above as well as those on Table I describing the conditions considered are to represent first-class operation. Local conditions vary a great deal.

By comparing actual local conditions with those used above a closer estimate can usually be made for any specific case. For instance, in some plants the exhaust from non-condensing engines may be used for steam heating, the revenue from which will effect a lower cost of power. In other cases where the load factor is low, the cost of attendance may be cut down if the firemen can be used for other work during the period of low power demand. The price of coal delivered in the furnace room depends largely upon railroad facilities and varies much at different points. Poor firing or defective equipment adds greatly to the cost of producing power. This matter is discussed further on page 13.

The costs per kilowatt hour were figured from the costs per brake horse power hour by adding to the total yearly expense on account of the added electrical machinery and by taking into account the different efficiencies of the electrical generators at the different load factors. From Mr. Wilson's tables initial costs of electrical generators were obtained and in the average case the fixed charges on these figure out to add about 8% to the total yearly expense. The following table of electric generator efficiencies was made up from a study of tests and from data of different authorities.

Load factor	*100 %*	*75%*	*50%*	*25%*
Op. by 100 and 200 H. P. Engines	85 %	80%	75%	70%
Op. by 400 and 600 H. P. Engines	87.5%	83%	79%	75%
Op. by 1,200 and 2,000 H. P. Engines	90 %	87%	84%	80%

NOTES ON GENERAL CONDITIONS

The figures at various load factors assume that the plant be operated so as to produce rated load at any time. The load factor is taken as the ratio of the average load to the full rated capacity of the plant, when both terms of the ratio refer only to the time during which the plant operates.

All figures dealing with fuel refer to moist coal. Moist coal with a heating value of 11,000 B. T. U. per pound corresponds to coal having 8.3% moisture and giving 12,000 B. T. U. per dry pound. Moist coal with a heating value of 9,000 B. T. U. per pound corresponds to coal having 10% moisture and giving 10,000 B. T. U. per dry pound.

TABLE I

ESTIMATED COSTS OF PRODUCING POWER WITH IOWA COALS

	Item No.		10 Hr Per Da—310 Da. Per Yr						24 Hr Per Da—365 Da. Per Yr						
At 100 Per Cent Load Factor	1	Rated I. H. P. of Plant	100	200	400	600	1200	3,000	100	200	400	600	1,200	3,000	
	2	No. of Units	2	3	3	4	4	4	2	3	3	4	4	4	
	3	Size of Each Unit, I. H. P.	100	100	200	200	400	1,000	100	100	200	200	400	1,000	
	4	No. of Boilers	2	3	4	4	3	4	2	3	4	4	3	4	
	5	Size of Each Boiler, H. P.	92	74	88	115	230	256	92	74	88	115	230	256	
	6	Brake H. P. of Plant	85	170	340	510	1020	2,550	85	170	340	510	1,020	2,550	
	7	Cost of Engines, Room and Equip.	51 72	52 50	50 05	45 06	41 60	31 55	51 72	52 50	50 05	45 06	41 60	31 55	Per I. H. P.
	8	Cost of Boilers	22 85	14 76	11 00	9 04	12 70	11 04	22 85	14 76	11 00	9 04	12 70	11 04	
	9	Cost of Boilers, Room and Equip.	58 65	38 62	28 70	22 22	25 61	18 29	58 65	38 62	28 70	22 22	25 61	18 29	
	10	Total Initial Cost	110 37	91 12	78 75	67 28	64 21	49 84	110 37	91 12	78 75	67 28	64 21	49 84	
	11	Fixed Charges—14%, on I. Cost	15 40	12 75	11 03	9 42	9 00	6 98	15 40	12 75	11 03	9 42	9 00	6 98	Per I. H. P. Year
	12	Oil and Waste	1 02	1 02	1 02	1 02	1 02	1 02	2 89	2 89	2 89	2 89	2 89	2 89	
	13	Attendance	15 53	10 85	7 56	6 35	4 65	3 72	43 80	30 66	21 57	17 96	13 14	10 41	
	14	Condensing Water			1 93	1 64	1 26	1 25			5 45	4 66	3 56	3 53	
	15	Boiler Pressure—Lbs. Per Sq. In.	100	120	120	120	150	150	100	120	120	120	150	150	
	16	Pounds of Steam Per I. H. P. Hr.	30	24	20	17	13	13	30	24	20	17	13	13	
	17	Pounds Water Evap. Per Lb. Coal	5 7	5 7	5 3	5 3	6 0	6 0	6 4	6 4	6 0	6 0	6 8	6 8	[illegible]
	18	Pounds Coal Per I. H. P. Hr.	5 26	4 22	3 78	3 20	2 17	2 17	4 69	3 74	3 34	2 84	1 92	1 92	
	19	Pounds Water Evap. Per Lb. Coal	4 3	4 3	4 0	4 0	4 5	4 5	4 8	4 8	4 5	4 5	5 1	5 1	[illegible]
	20	Pounds Coal Per I. H. P. Hr.	7 00	5 60	5 00	4 25	2 90	2 90	6 20	4 98	4 45	3 78	2 55	2 55	
	21	Cost of Coal Per I. H. P. Yr.	24 40	19 60	17 60	14 80	10 20	10 20	61 30	49 20	44 10	37 20	25 40	25 40	[illegible]
	22	Cost of Coal Per I. H. P. Yr.	21 60	17 30	15 60	13 10	9 10	9 10	54 30	43 70	39 00	32 90	22 50	22 50	[illegible]
	23	Total Cost Per I. H. P. Yr. 100% L. F.	56 32	44 22	39 14	33 23	25 13	23 1[illegible]	125 89	95 6[illegible]	84 87	77 11	54 86	49 59	
	24	" " " " 75% "	53 25	41 77	36 94	31 01	23 85	21 6[illegible]	115 71	89 44	78 83	69 44	50 86	44 52	
	25	" " " " 50% "	50 22	39 32	34 55	28 65	22 45	19 9[illegible]	108 0[illegible]	83 27	72 78	60 55	47 28	41 39	
	26	" " " " 25% "	47 17	36 86	32 16	26 61	21 05	18 5[illegible]	100 37	77 16	67 43	55 37	43 73	37 82	

TABLE I—Cont'd

Item No.			[illegible] Hr. Per Da.—[illegible] Da. Per Yr.						24 Hr. Per Da.—365 Da. Per Yr.						
27	Total Cost Per B. H. P. Yr.	100% L. F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28		75% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
29		50% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
30		25% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
31	Cost Per B. H. P. Hr.	100% L. F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
32		75% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
33		50% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
34		25% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
35	Total Cost Per [illegible]	100% L. F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36		75% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
37		50% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
38		25% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
39	Total Cost Per [illegible]	100% L. F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
40		75% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
41		50% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
42		25% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
43	Cost Per [illegible] Hr.	100% L. F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
44		75% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
45		50% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
46		25% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
47	Cost Per K. W. Hr.	100% L. F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
48		75% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
49		50% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
50		25% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
51	Cost Per K. W. Hr.	100% L. F.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
52		75% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
53		50% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
54		25% "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

EXPLANATION OF ITEMS ON TABLE I

The left hand margin of Table I shows which general items are figured at 100% load factor. The right hand margin shows on what basis the general costs are figured and with what price of coal each particular cost is figured.

All costs are given in dollars except those for brake horse power hours and kilowatt hours which are given in cents.

Item 1 gives the rated indicated horse power of the plant upon which the yearly expenses are calculated.

Items 2, 3, 4, and 5 show the actual number and rated capacity of engines and boilers including one reserve engine and boiler in each plant. It may be noted that for the larger plants the rated horse power of boilers is low when compared with the engine horse power. This is explained by the fact that the larger engines require less steam per horse power hour.

Item 6 gives the estimated brake horse power of the plant which represents the actual mechanical horse power delivered by the fly wheel to engine belt at full rated capacity.

Item 7 includes the cost of engine room and every thing in it except the electrical machinery.

Items 7-10 give the costs per rated indicated horse power.

Item 9 includes the cost of stack, boiler room and everything in the boiler room.

Items 11-14 give the yearly expenses per rated indicated horse power.

Item 10 includes the entire cost of plant per rated indicated horse power exclusive of the electrical machinery.

The electrical machinery is not considered before item 47 because the object is first to arrive at a cost of purely mechanical power.

Item 17 gives the pounds of water evaporated per pound of moist fuel. These amounts vary with constant boiler efficiency because of the different temperatures at which the water is fed to the boiler.

The costs per indicated horse power year and per brake horse power year are based upon the rated indicated horse power and brake horse power respectively, and not upon the power actually developed at the various load factors below 100%.

The costs per brake horse power hour and per kilowatt hour are based upon the power actually delivered to the belt and to the switch board respectively.

EQUIPMENT OF PLANTS ON TABLE I

100 I. H. P. Plant: Simple, non-condensing, high speed engines. Fire tube boilers.
200 I. H. P. Plant: Compound, non-condensing, high speed engines. Fire tube boilers.
400 I. H. P. Plant: Compound, condensing, high speed engines. Fire tube boilers.
600 I. H. P. Plant: De Laval turbines. Fire tube boilers.
1,200 I. H. P. Plant: Horizontal, condensing, low speed, Corliss engines. Water tube boilers.
2,000 I. H. P. Plant: Parson's turbines. Water tube boilers.

CALCULATIONS OF POWER COSTS FOR ANY PARTICULAR PLANT

The expense items have been separated somewhat to show how the final results have been reached. The separation of expenses is of value when the reader wishes to calculate costs where certain conditions are far from the ordinary. It is not supposed that any one plant will closely approach the "average" conditions as assumed in working out the figures on Table I. Large variations may occur in the initial cost of the plant, price of coal, or efficiency of machinery.

By comparing the items of expense in an actual case with those given for the corresponding "estimated" case, a net difference of costs will be obtained. Then by adding or subtracting (as the case may call for) this net difference from the "estimated" cost per rated indicated horse power year a new cost per rated indicated horse power year for the "actual" case will be obtained. This "actual" total cost, divided by the "estimated" total cost, will then form a ratio of total costs. This ratio multiplied by the "estimated" costs per brake horse power hour or per kilowatt hour given for the corresponding case, will give the calculated costs for producing these units of energy under the "actual" conditions. The following example is worked out to illustrate the above explanation.

Given: An electric power plant rated at 400 indicated horse power; 4 second hand boilers costing, with settings, $3,000.00, and operating at 45% efficiency because of poor setting and careless firing; 11,000 B. T. U. coal costing $3.50 per ton because of distance from mine; load factor, 50%; all other costs and conditions practically the same as in "estimated" case of 400 H. P. plant operating 10 hours per day, 310 days per year. Calculate by referring to Table I, the costs per brake horse power hour and per kilowatt hour.

CALCULATIONS:

$3,000.00 ÷ 400 = $7.50, initial cost of boilers and settings per rated indicated horse power.

$7.50 is $3.50 less than $11.00, the estimated cost.

14% x $3.50 = $0.49, fixed charge, saved per I. H. P. year on initial cost of boilers.

60% (estimated efficiency) ÷ 45% = 1.333. That is, the low efficiency boilers would require one-third more coal. This, multiplied by the ratio of coal costs per ton, will give the ratio of coal cost per rated indicated horse power year. The ratio of coal cost per ton is:

$3.50 ÷ $3.00 = 1.1666.

1.333 x 1.1666 = 1.555, the ratio of coal cost. That is, under the conditions of this example the total coal cost per year will be 55.5% more than the estimated cost, or:

55.5% x $17.60 x 75% = $7.32, the added coal cost per rated indicated horse power year.

In the above equation, $17.60 is the estimated coal cost per rated indicated horse power year at 100% load factor and 75% is the percentage of coal required at 50% load factor.

Total cost added per rated I. H. P. year..........	$7.32
Total cost saved " " " "	0.49
Net cost added " " " "	$6.83

Estimated total cost per rated I. H. P. year at 50% load factor, with $3.00 coal is $34.55.

$34.55 + $6.83 = $41.38, total cost per rated I. H. P. year for this example.

$41.38 ÷ $34.55 = 1.19, ratio of total costs.

1.19 x 2.62c (estimated) = *3.13c*, calculated cost per actual B. H. P. hour for this particular plant.

1.19 x 4.77c (estimated) = *5.70c*, calculated cost per K. W. hour for this particular plant.

CURVE SHEETS

Figs. 1, 2, 3 and 4 are curve sheets showing graphically the estimated costs per brake horse power hour for 10 and 24 hour operation, with 9,000 B. T. U. coal at $2.00 and with 11,000 B. T. U. coal at $3.00, all with 100%, 75%, 50% and 25% load factors. Curves on Figs. 1 and 2 are plotted from items 31 to 34 of Table I. Curves on Figs. 3 and 4 are plotted from items 43 to 46 of Table I.

Figs. 5 to 20 constitute a second set of curve sheets showing estimated costs per brake horse power hour with coals costing from $1.00 to $6.00 per 2,000 pounds. These curves show also the costs of coal per brake horse power hour as separated from all other costs. The curve bordering the upper side of the shaded portion represents the total of all expenses except that of coal. Each of the upper curves represents the total cost with coal at the particular price with which the curve is marked.

For example, suppose one wishes to find the total cost and the fuel cost per brake horse power hour in a 1,200 horse power plant operating ten hours per day, 310 days per year, at 25% load factor, with 9,000 B. T. U. coal costing $3.00 per 2,000 pounds.

Turning to Fig. 12 which corresponds to the conditions given, it is seen that the "$3.00" curve indicates 3.5 cents as the total cost per brake horse power hour. Dropping down to the curve bordering the shaded portion, it is seen that 2.15 cents is the total cost per brake horse power hour exclusive of coal. Subtracting 2.15 cents from 3.5 cents leaves 1.35 cents per brake horse power hour due to coal.

Table II gives the figures from which these curves were plotted. The costs to be added for each dollar that the coal costs per 2,000 pounds are given to be used in calculations where the cost per 2,000 pounds is not in even dollars.

It will be noticed that Table II has the same arrangement of conditions as has Table I. Table II also has an index of figure numbers referring to curve sheets corresponding to each particular condition.

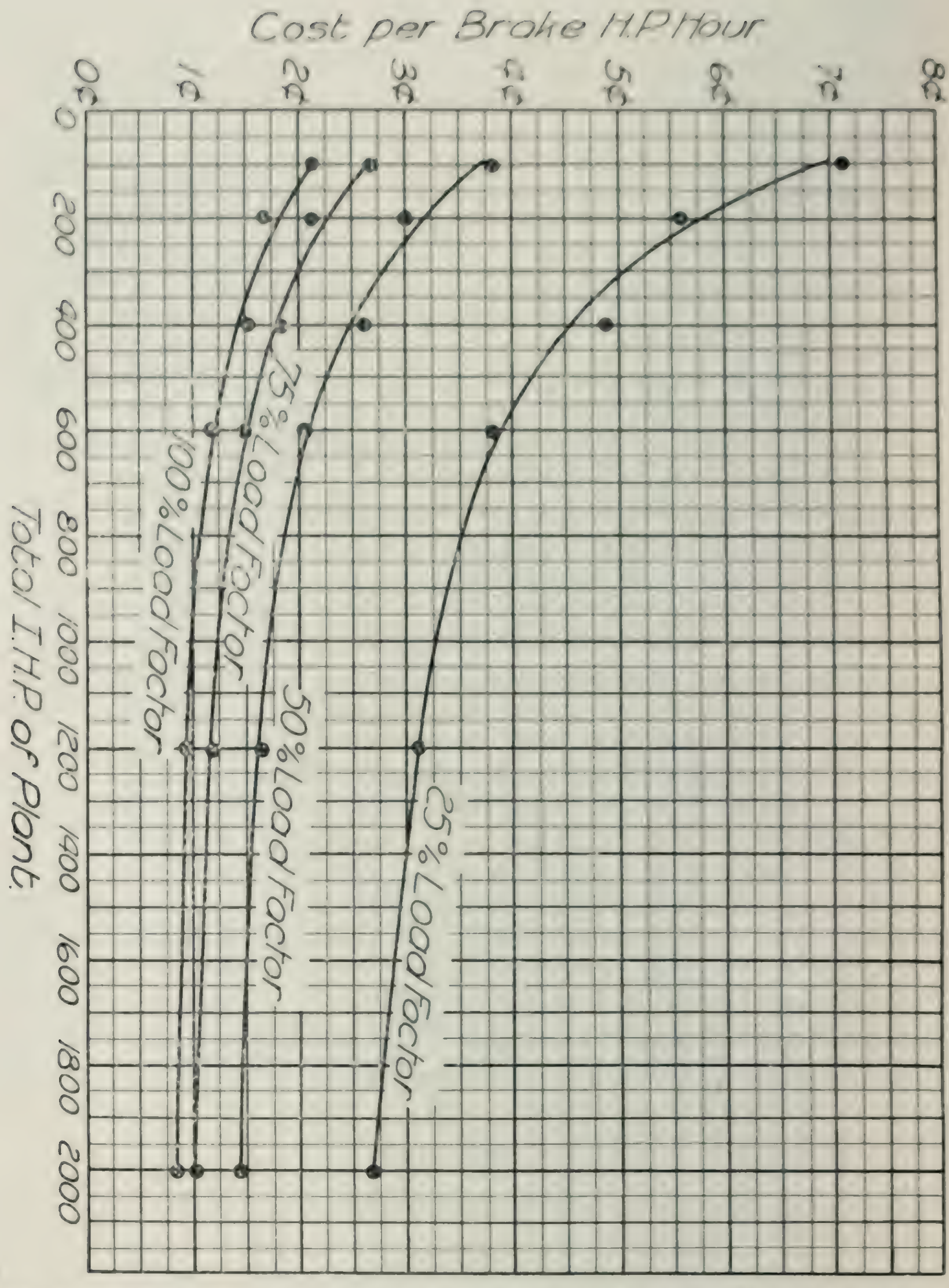

Fig. 1. 10 hr. per day, 310 days per year, 11,000 B. T. U. coal @ $3.00.

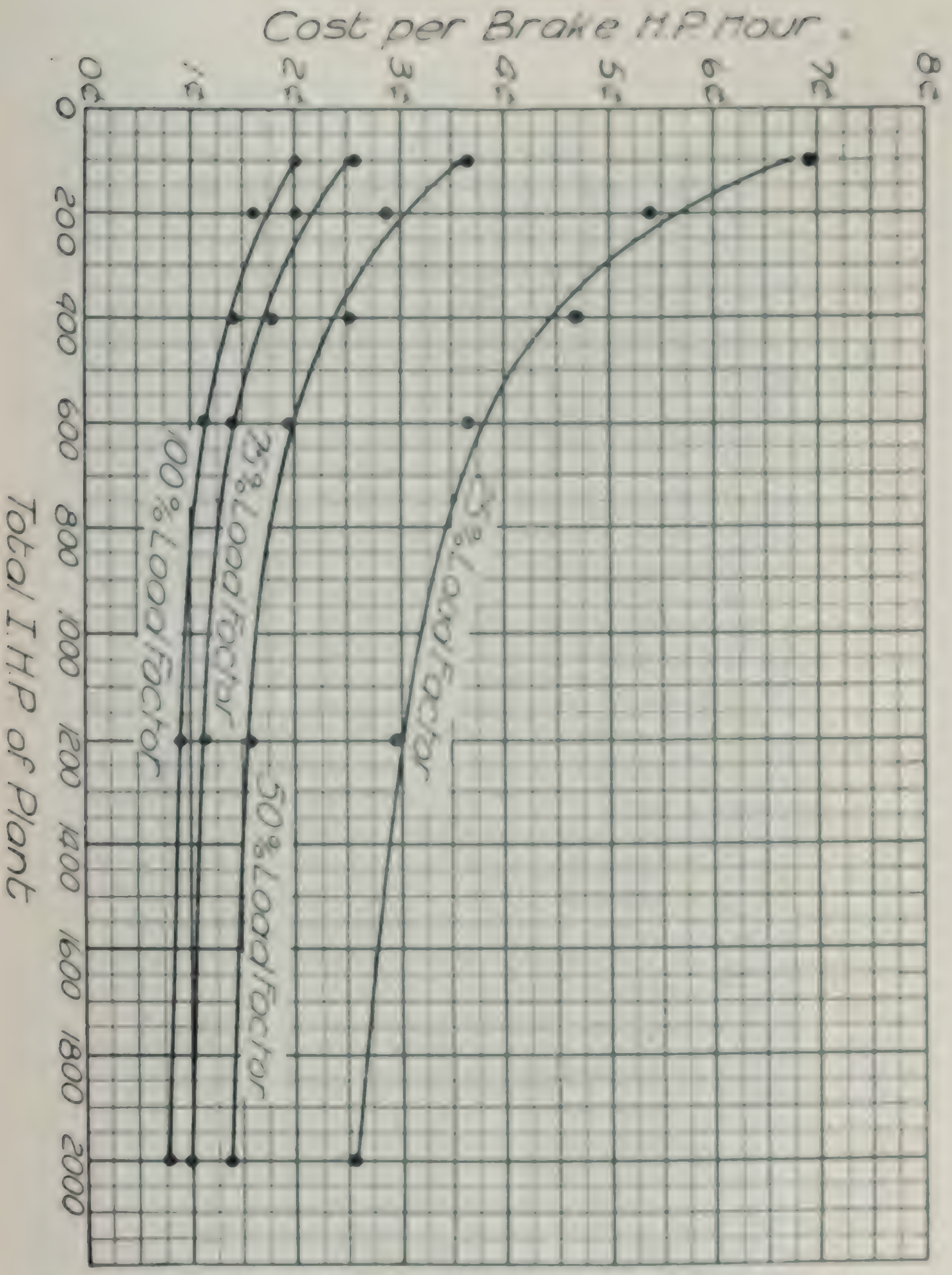

Fig. 2. 10 hr. per day, 310 days per year, 9,000 B. T. U. coal @ $2.00.

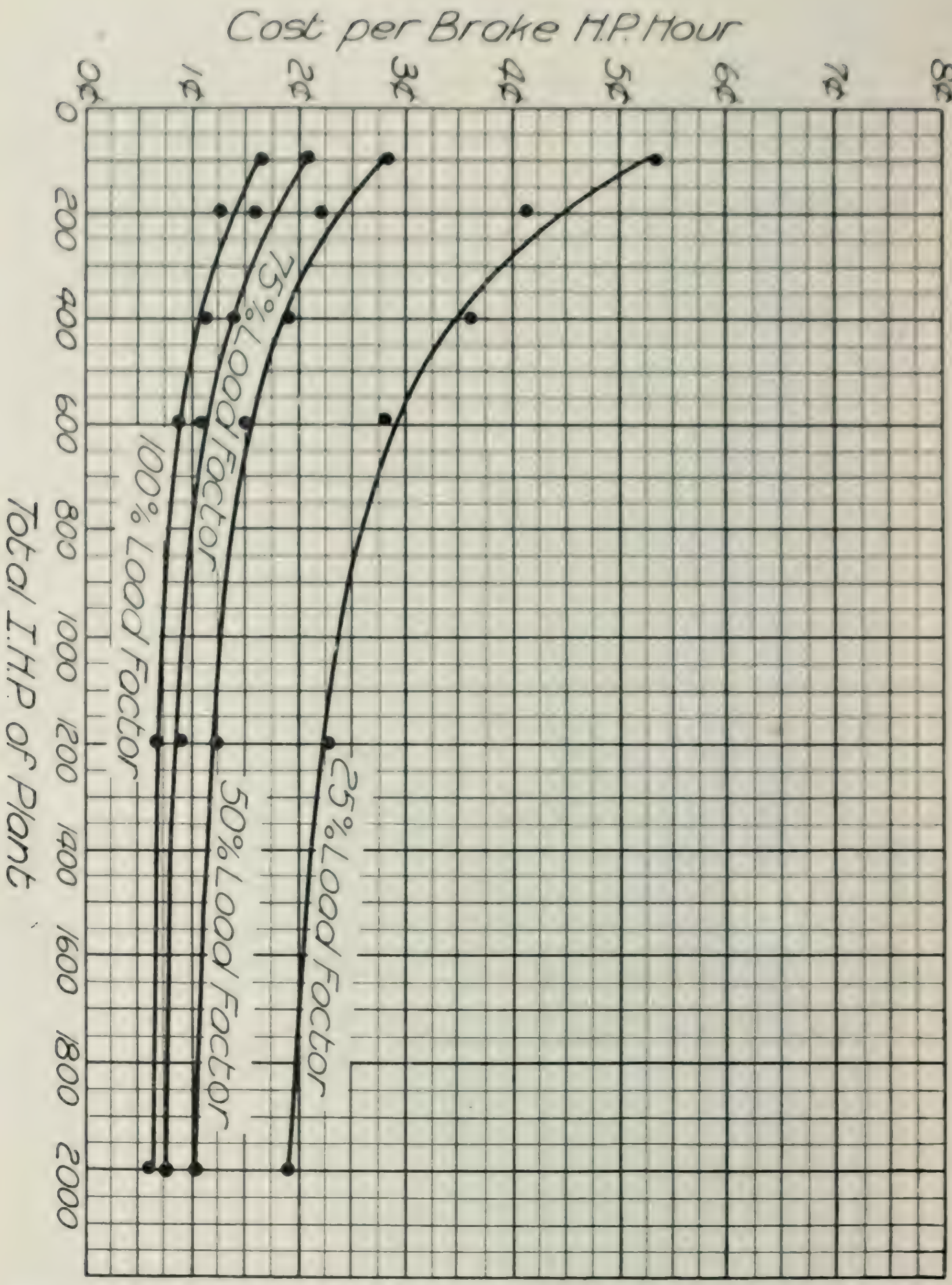

Fig. 3. 24 hr. per day, 365 days per year, 11,000 B. T. U. coal @ $3.00.

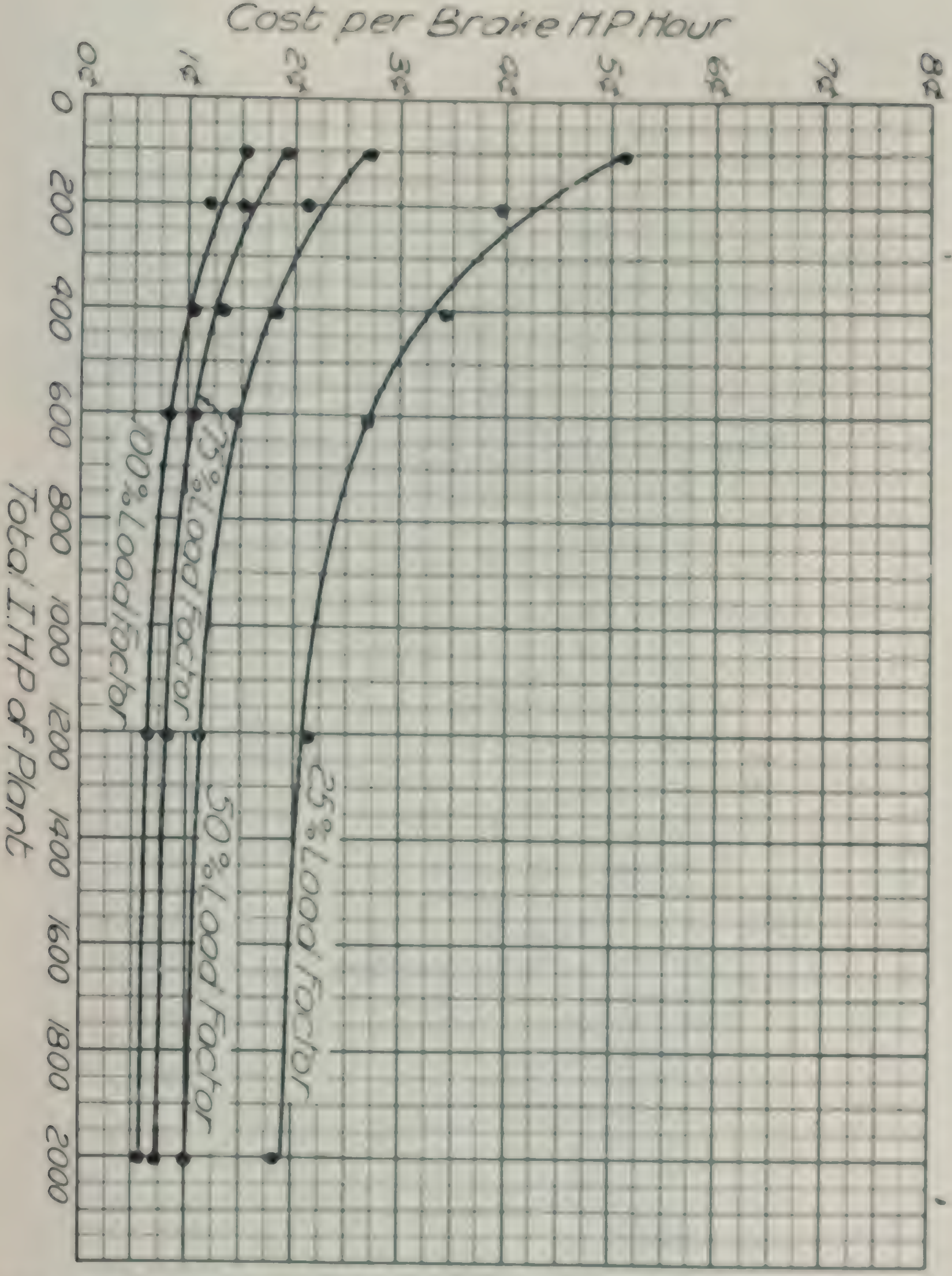

Fig. 4. 24 hr. per day, 365 days per year, 9,000 B. T. U. coal @ $2.00.

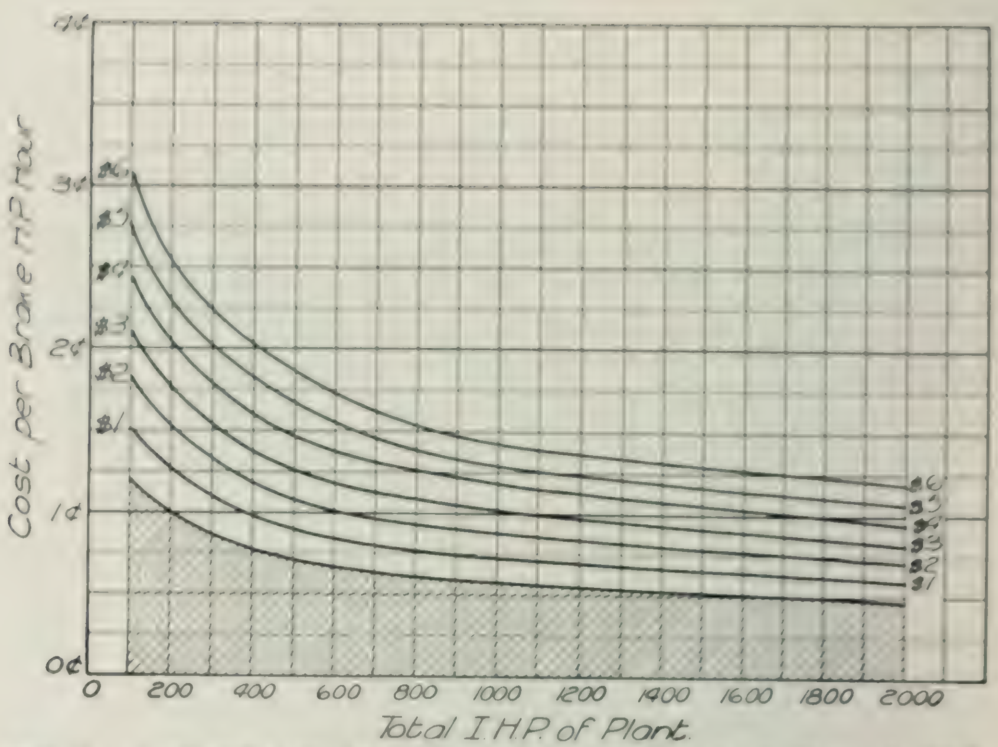

Fig. 5. 10 hr. per day, 310 days per year, 11,000 B. T. U. coal, 100% load factor.

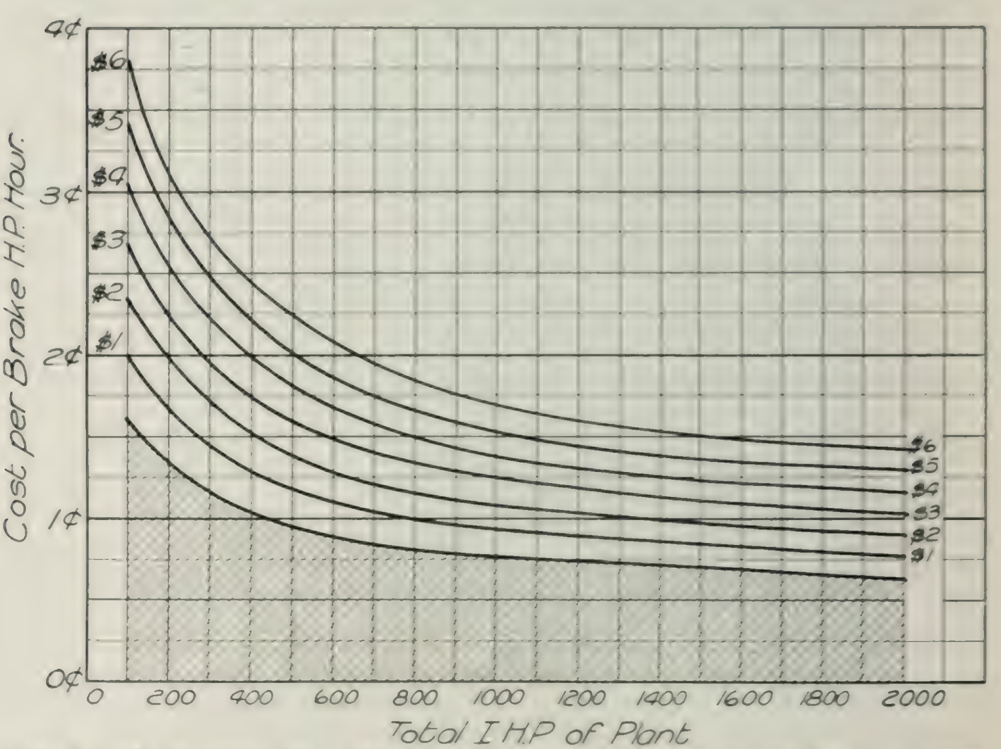

Fig. 6. 10 hr. per day, 310 days per year, 11,000 B. T. U. coal, 75% load factor.

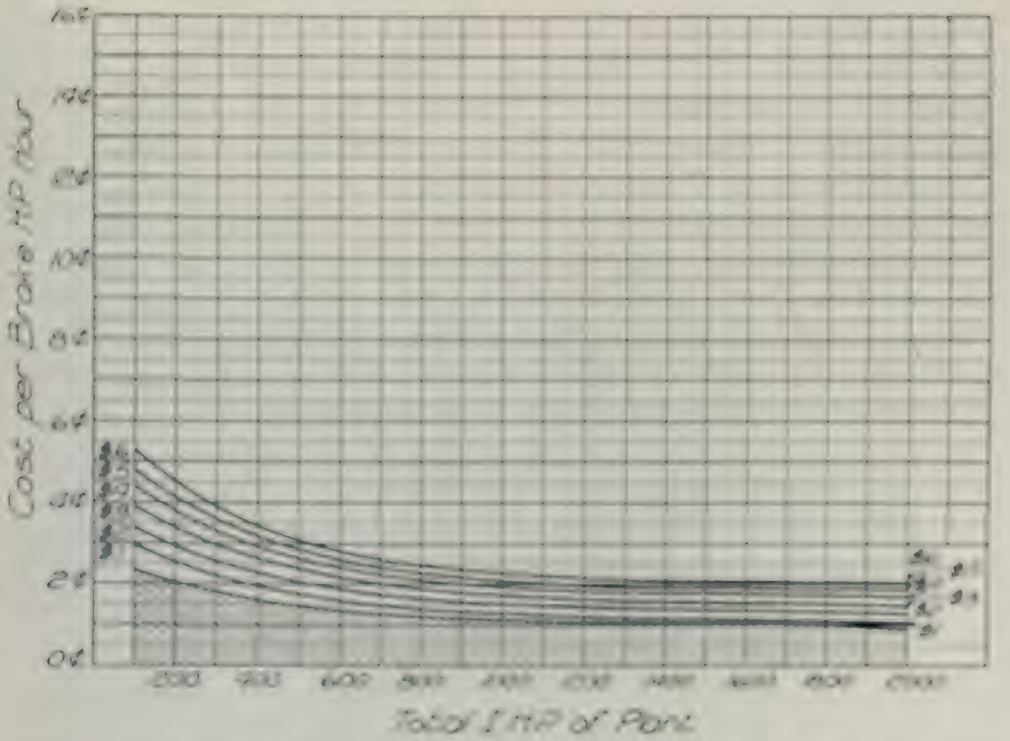

Fig. 7. 10 hr. per day, 310 days per year, 11,000 B. T. U. coal, 10% load factor.

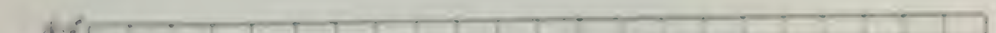

Fig. 8. 10 hr. per day, 310 days per year, 11,000 B. T. U. coal, 25% load factor.

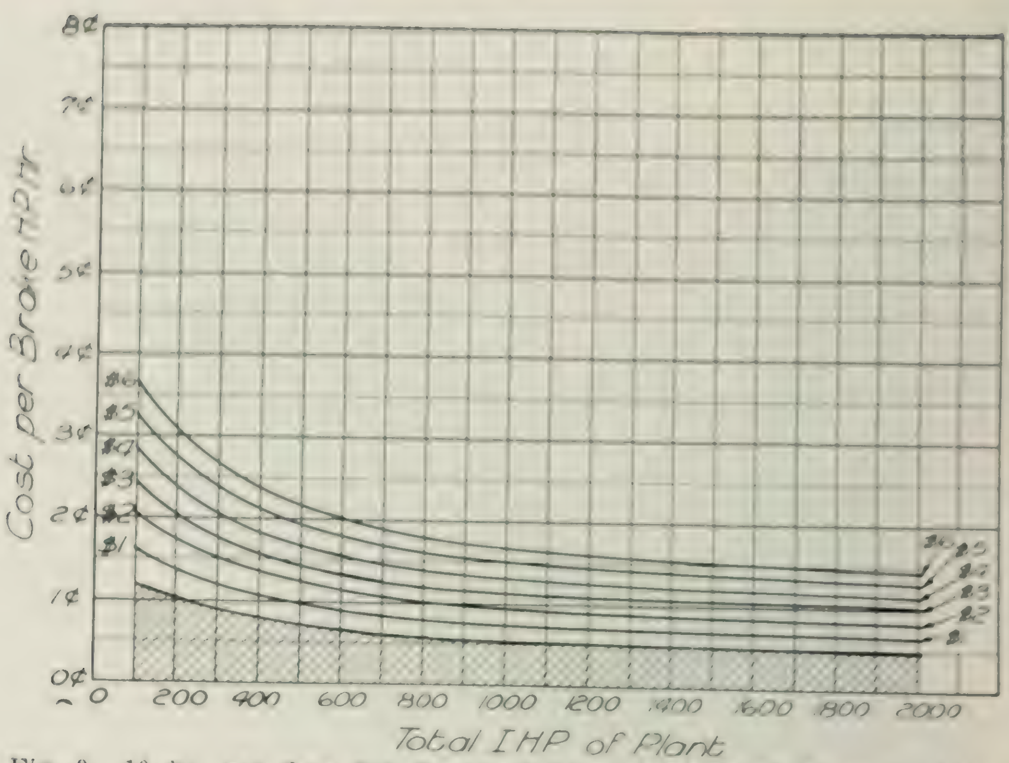

Fig. 9. 10 hr. per day, 310 days per year, 9,000 B. T. U. coal, 100% load factor.

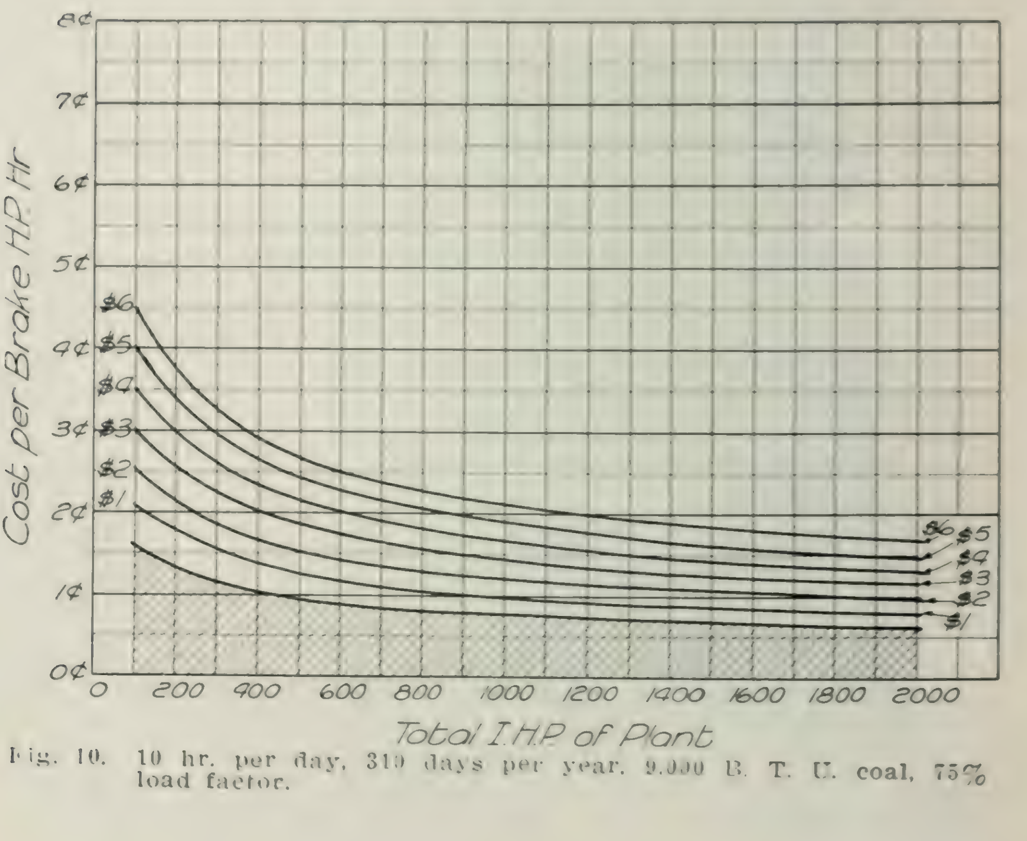

Fig. 10. 10 hr. per day, 310 days per year, 9,000 B. T. U. coal, 75% load factor.

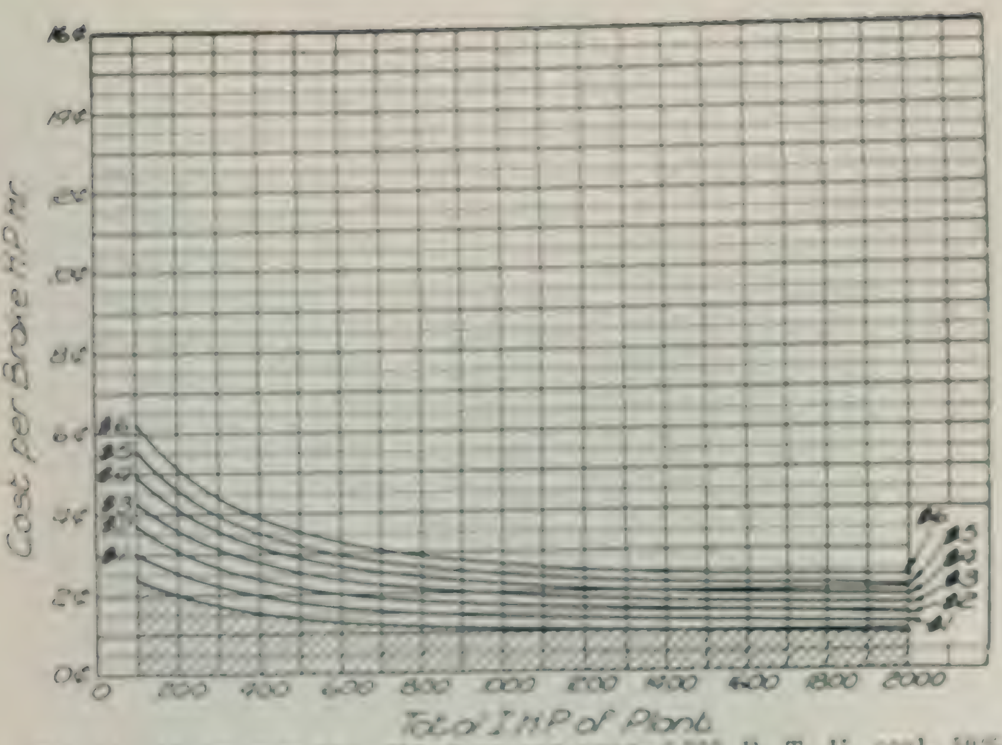

Fig. 11. 10 hr. per day, 310 days per year, 9,000 B. T. U. coal, 50% load factor.

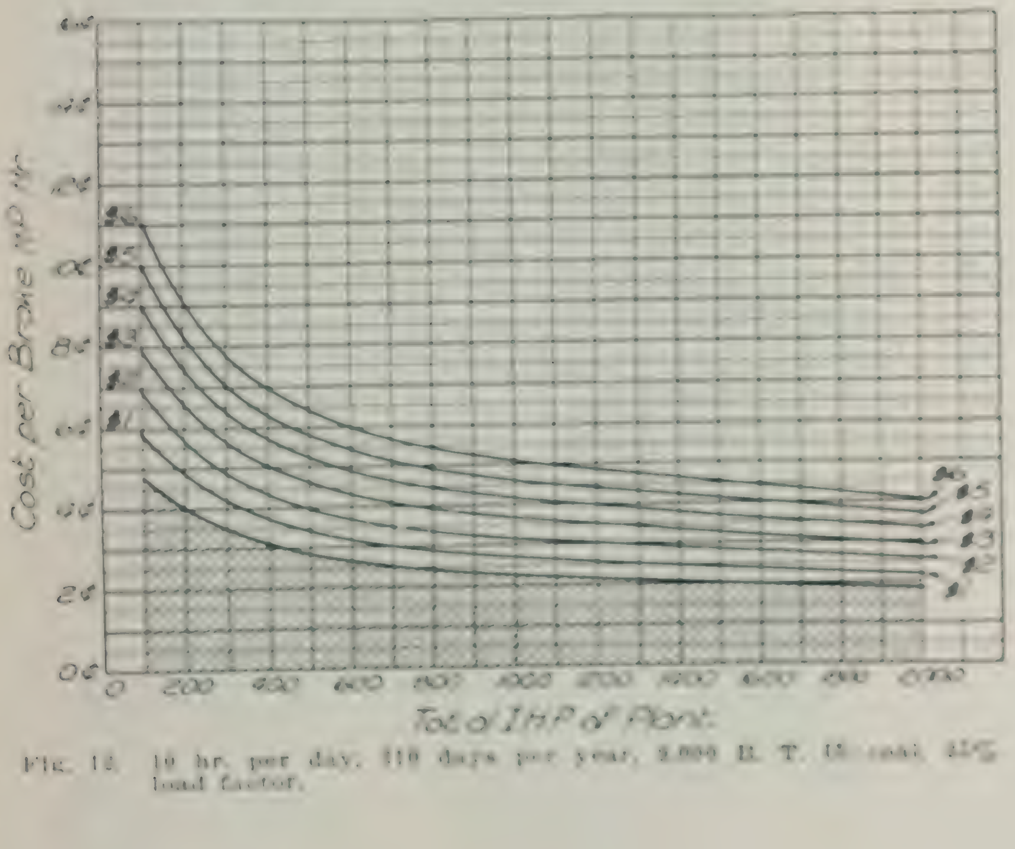

Fig. 12. 10 hr. per day, 310 days per year, 8,000 B. T. U. coal, 25% load factor.

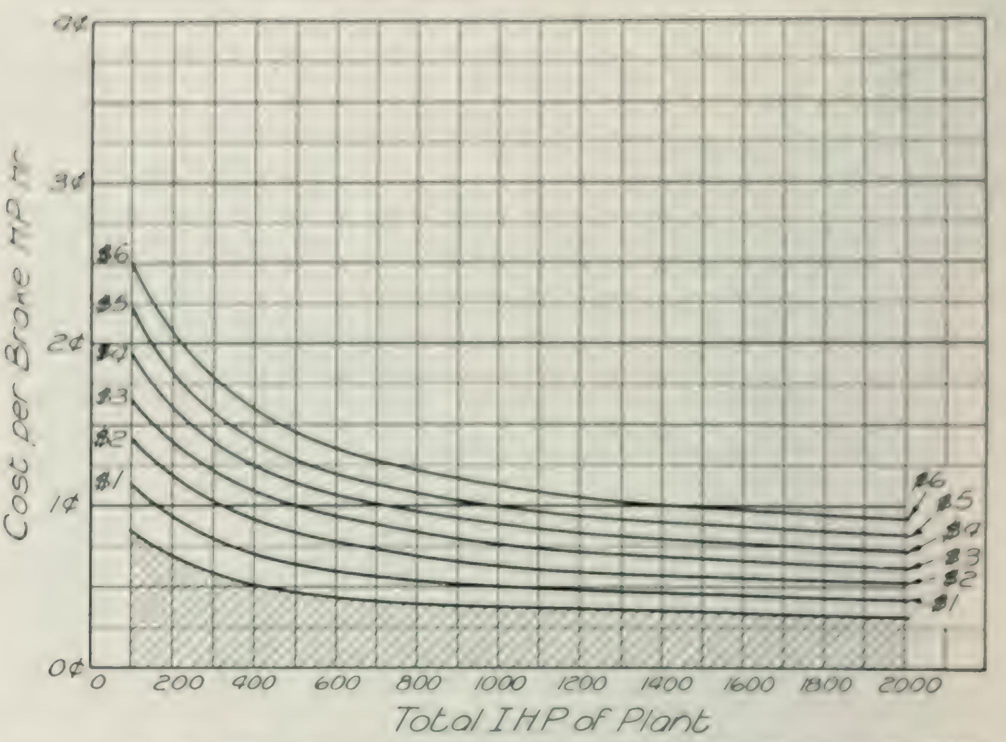

Fig. 13. 24 hr. per day, 365 days per year, 11,000 B. T. U. coal, 100% load factor.

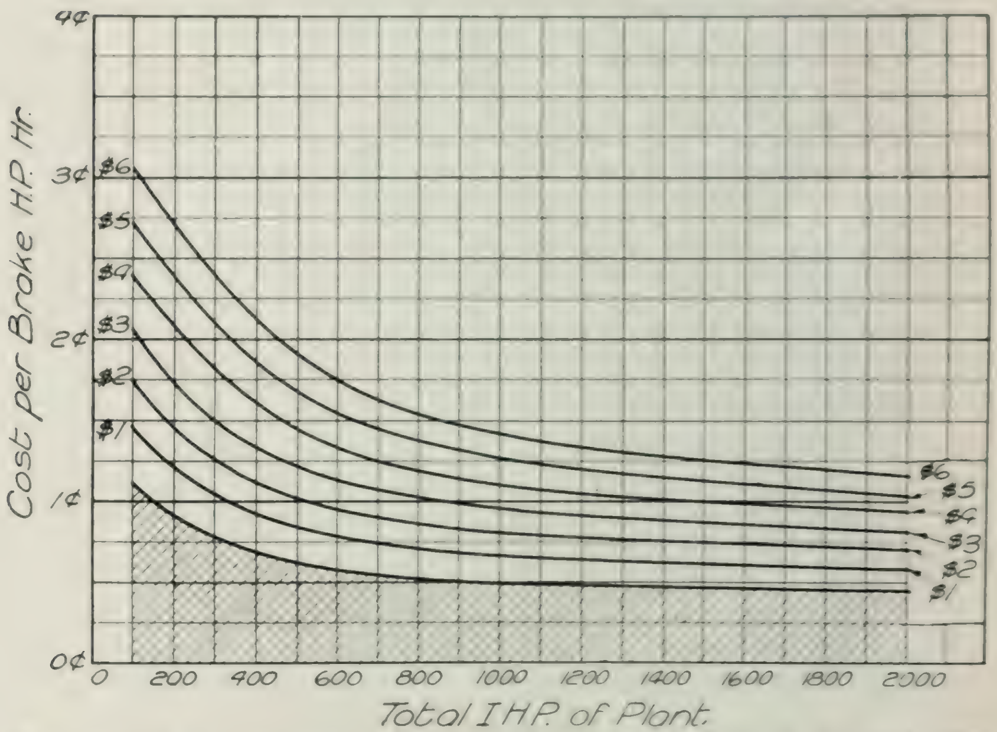

Fig. 14. 24 hr. per day, 365 days per year, 11,000 B. T. U. coal, 75% load factor.

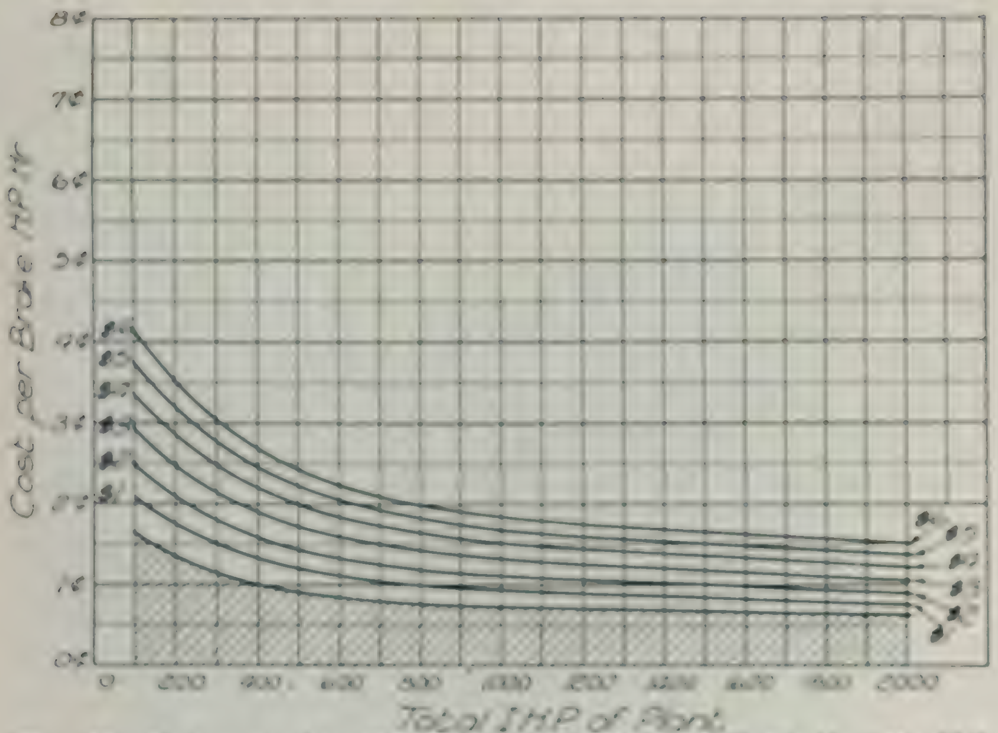

Fig. 15. 24 hr. per day, 365 days per year, 11,000 B. T. U. coal, 10% load factor.

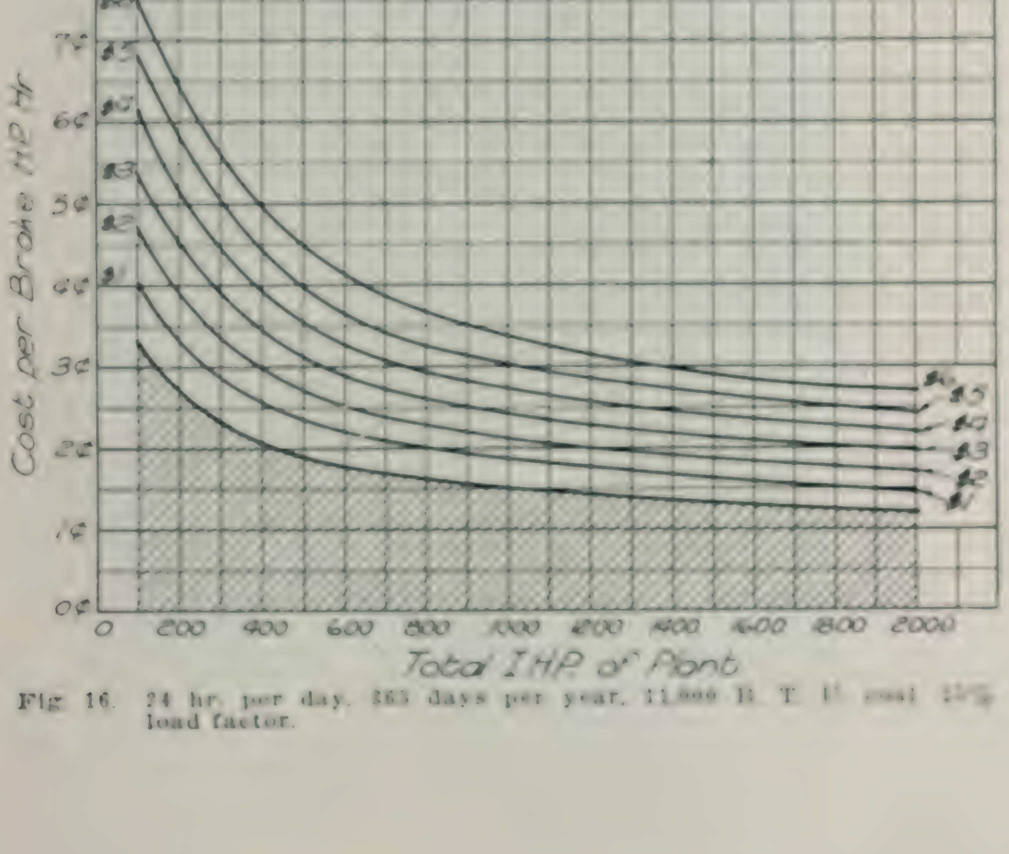

Fig. 16. 24 hr. per day, 365 days per year, 11,000 B. T. U. coal 15% load factor.

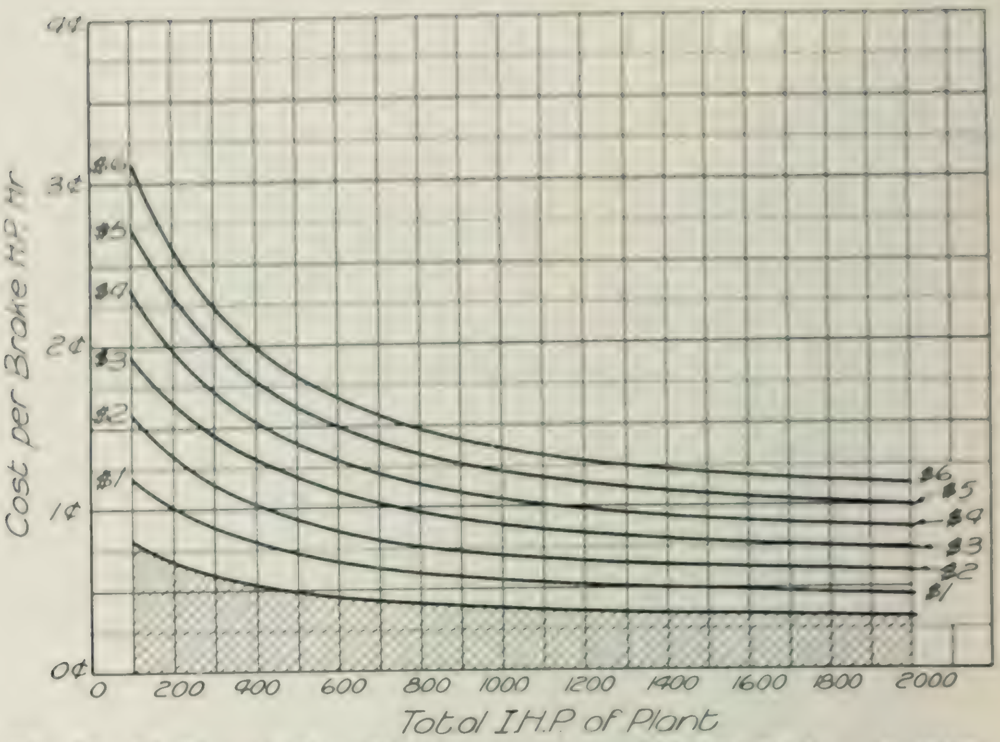

Fig. 17. 24 hr. per day, 365 days per year, 9.000 B. T. U. coal, 100% load factor.

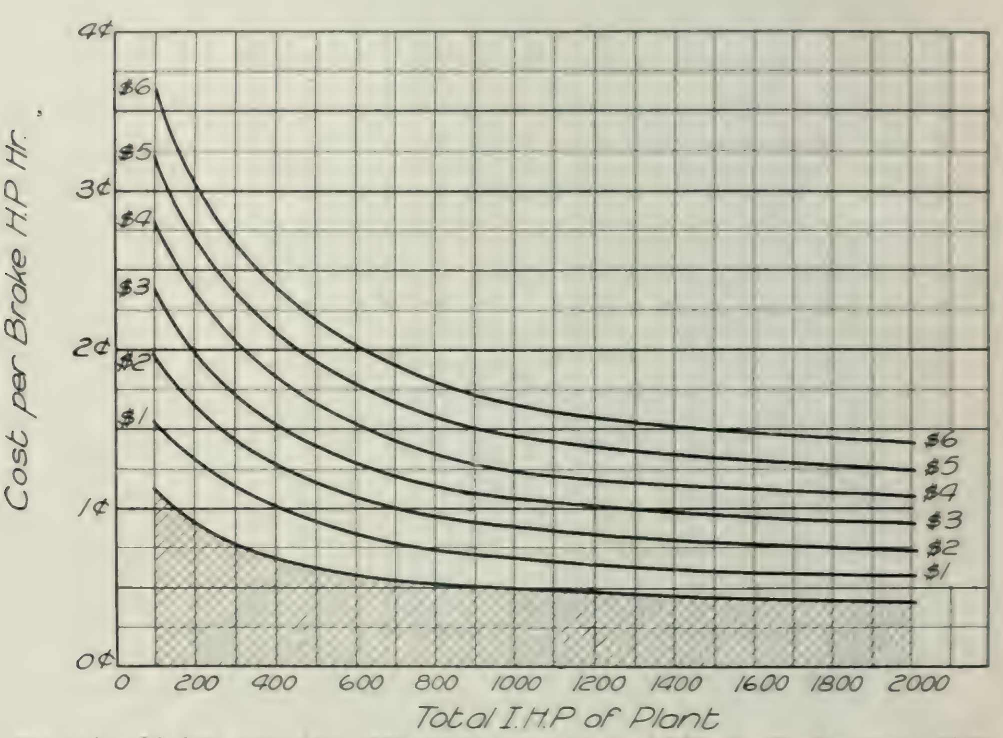

Fig. 18. 24 hr. per day, 365 days per year, 9.000 B. T. U. coal, 75% load factor.

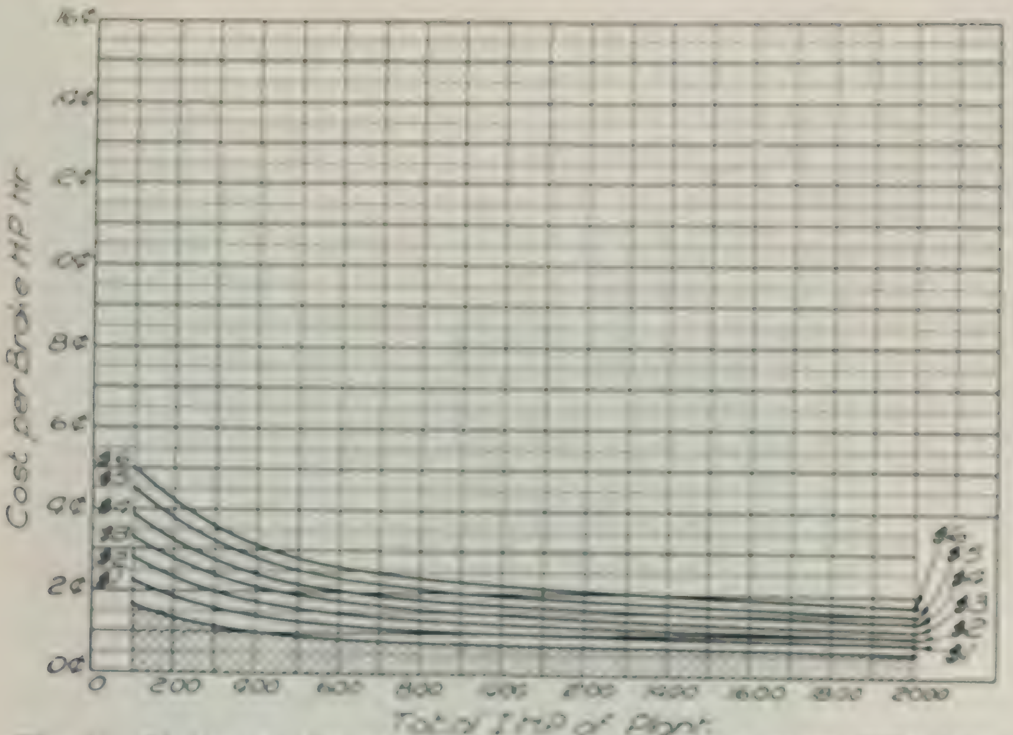

Fig. 19. 24 hr. per day, 183 days per year, 9,000 B. T. U. coal, 10% load factor.

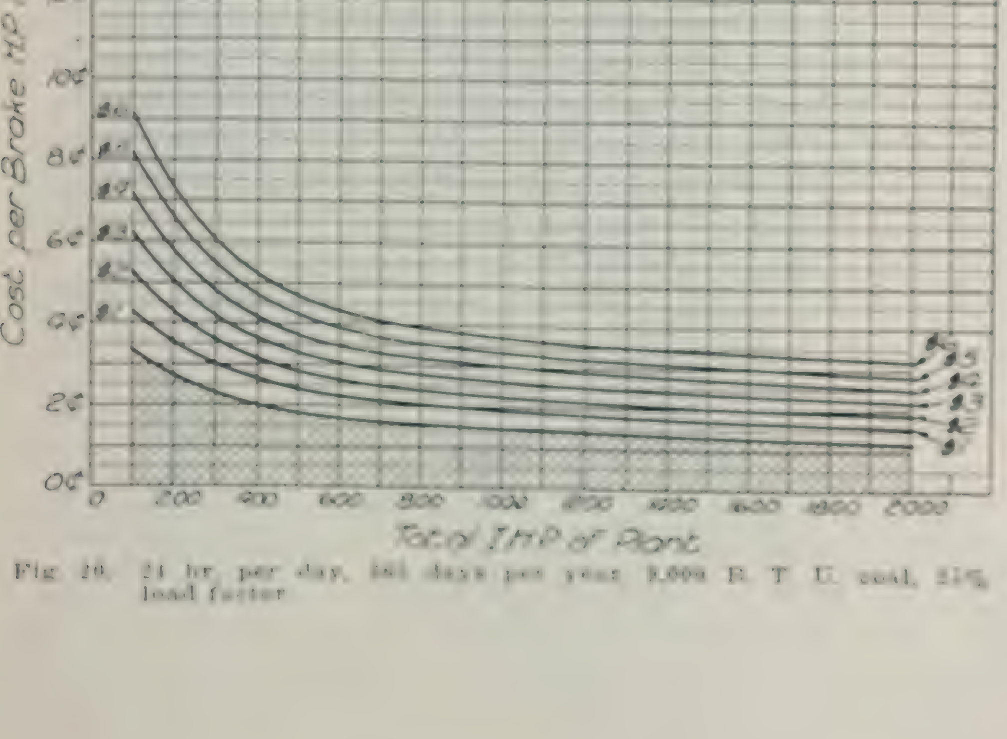

Fig. 20. 24 hr. per day, 365 days per year, 9,000 B. T. U. coal, 25% load factor.

TABLE II

TOTAL COST IN CENTS PER BRAKE HORSE POWER HOUR.

		10 Hr. x 310 Da.						24 Hr. x 365 Da.							
		Rated I. H. P. of Plant							Rated I. H. P. of Plant						
Fig. No.		100	200	400	600	1,200	2,000	Fig. No.	100	200	400	600	1,200	2,000	
5	100% L. F.	.31 1.21	.25 .94	.22 .82	.18 .66	.13 .55	.12 .47	13	.27 .83	.22 .62	.20 .54	.16 .44	.11 .37	.10 .31	11,000 B. T. U. Coal
6	75% L. F.	.36 1.62	.28 1.26	.26 1.09	.20 .88	.14 .74	.13 .62	14	.32 1.11	.26 .83	.24 .71	.18 .58	.13 .49	.12 .40	
7	50% L. F.	.46 2.43	.37 1.88	.33 1.62	.25 1.31	.19 1.09	.17 .92	15	.41 1.65	.33 1.24	.30 1.06	.22 .86	.17 .73	.15 .59	
8	25% L. F.	.77 4.85	.62 3.75	.56 3.21	.40 2.61	.31 2.17	.28 1.83	16	.68 3.31	.55 2.48	.49 2.13	.36 1.72	.28 1.46	.25 1.18	
9	100% L. F.	.41 1.21	.33 .94	.30 .82	.23 .66	.17 .55	.16 .47	17	.37 .83	.30 .62	.27 .54	.21 .44	.15 .37	.14 .31	9,000 B. T. U. Coal
10	75% L. F.	.48 1.62	.39 1.26	.35 1.09	.27 .88	.20 .74	.18 .62	18	.42 1.11	.35 .83	.33 .71	.24 .58	.18 .49	.17 .40	
11	50% L. F.	.62 2.43	.49 1.88	.45 1.62	.33 1.31	.25 1.09	.23 .92	19	.55 1.65	.45 1.24	.41 1.06	.30 .86	.22 .73	.21 .59	
12	25% L. F.	1.03 4.85	.85 3.75	.74 3.21	.55 2.61	.43 2.17	.38 1.83	20	.93 3.31	.75 2.48	.67 2.13	.49 1.72	.38 1.46	.33 1.18	

The lower figures in each square are the costs exclusive of coal. The upper figures in each square represent the amounts to be added for each dollar that the coal costs per 2,000 pounds.

POWER PLANT TESTS IN IOWA

Table III gives results of tests on Iowa power plants and supplies approximate figures on the cost of generating power in Iowa with Iowa coals in electric power plants of the capacities noted on data sheet.

All figures are based upon a one day's test of each respective plant and upon the assumption that the plant is operated the same each day of the year. These tests were practically all run during the winter months and under the ordinary load conditions. The readings were taken and the results calculated by students of the Iowa State College under the direction of instructors in the Mechanical and Electrical Engineering departments of the college. These figures were arranged and reduced to a comparative basis by the Engineering Experiment Station.

The costs arrived at are not claimed to be entirely accurate. The greatest discrepancy would perhaps be in the valuation of the power plant or in fixing the operating expenses. It will be noted that the estimated value per rated indicated horse power ranges from $50.00 to $133.00 for plants of 200 indicated horse power or under.

Only the engines and boilers actually used in the tests are given in the table. Any reserve units are mentioned in the notes on equipment. The total cost of plants, however, includes the reserve units.

The pounds of steam per indicated horse power hour represent dry steam and include that used for auxiliaries in practically all cases.

Efficiency of conversion is the combined mechanical efficiency of the engine and the efficiency of the electric generator.

All costs are based upon 365 days of operation per year.

The cost per brake horse power hour is calculated from the cost per indicated horse power hour by assuming approximately equal losses of conversion in the engine and generator.

The cost per brake horse power hour includes fixed charges on the electrical equipment of the station, while on Table I it does not. The difference amounts to about eight or ten per cent.

TABLE III

COSTS OF PRODUCING POWER
BASED ON ACTUAL TESTS WITH IOWA COALS.

1	Plant No.	1	2	3	4	5	6	7	8	9	10	Aver.
2	Year of Test	1907	1908	1907	1909	1908	1906	1907	1912	1912	1910	
3	Hrs. Operated Per Da.	16	11	24	18	24	12	15	24	24	12	18 6
4	No. of Engines Operated	1	1	2	2	1	1	2	1	2	1	
5	Total I. H. P. of Engines Operated	80	100	115	120	150	165	200	250	375	750	220 5
6	No. of Boilers Operated	2	1	2	2	1	2	2	1	2	2	
7	Total H. P. of Boilers Operated	200	100	140	110	200	200	200	150	400	1,000	270
8	Total Cost of Plant		8,000	8,027	6,000	20,000	20,000	11,800	19,550	25,400	25,000	15,604
9	Total Cost of Plant, Per I. H. P.		80	70	50	133	121	59	66	67	33	73 50
10	" " " " " B. H. P.		102	88	65	173	155	72	86	75	35	94 60
11	Fixed Charges Per I. H. P. Yr.		10 40	10 40	9 00	17 70	14 20	10 70	7 45	9 65	4 60	10 25
12	Operating Expenses Per I. H. P. Yr.		23 70	48 60	30 00	29 10	25 00	26 30	29 90	32 45	11 40	28 50
13	Total Expenses Per I. H. P. Yr.		34 10	59 00	39 00	46 80	39 20	37 00	37 35	42 10	16 00	38 85
14	Cost of Coal Per 2,000 lbs. Delivered	2 17	2 22	2 00	3 70	3 30	1 80	2 36	1 65	2 74	1 51	2 36
15	B.T. U Per Lb., Moist Coal	8,750	10,250	8,850	12,900	11,440	9,800	10,280	8,930	11,000	9,520	10,150
16	" " " Dry "	9,700	11,525	9,670	13,550	13,800	10,300	11,460	9,870	11,980	10,160	11,200
17	Boiler Pressure—Gauge	90	70	77	100	100	57	90	80	125	105	90
18	Lbs. of Steam Per Actual I. H. P. Hr.	46 4	42	34	39	29	34	39	35 5	33	25	35 5
19	Lbs. of Water Evap. Per Lb. Moist Fuel	4 7	6 0	4 1	6 4	4 7	5 7	5 7	4 8	7 87	4 5	5 47
20	Equiv. Evap. From & at 212° Per Lb. Moist Fuel	5 1	6 2	4 6	6 9	5 1	6 0	6 3	5 1	8 0	5 1	5 85
21	Efficiency of Boiler & Grate (%)	57	47	46	52	44	53	53	47	65	59	51 4
22	" (%) " Conversion	62	55	60	53	50	56	73	53	81	70	61 3
23	" (%) " Plant—Coal Pile to Sw'B'd	1 7	1 33	1 9	2 0	1 83	2 6	2 62	3 24	2 39	2 9	2 37
24	Load Factor, based on Peak—Time Operated	50	57	45	54	26	53	47	47	38	62	489
25	L. F. based on I. H. P.—365 Da.—Time Operated	37	32	37	25	23	36	40	21	27	30	31
26	L. F. based on I. H. P.—365 Da.—24 Hr. Per Da.	25	15	37	19	23	18	25	21	27	15	22
27	Ave. I. H. P. During Run	30	32	43	30	35	59	80	53	101	285	74 8
28	Cost Per Actual I. H. P. Hr.	2 4	2 5	1 9	2 4	2 3	2 5	1 65	2 0	1 8	0 96	2 04
29	Ave. B. H. P. During Run	24	25	34	23	27	46	67	41	91	240	61 8
30	Cost Per B. H. P. Hr.	3 0	3 2	2 4	3 1	3 0	3 2	2 0	2 6	2 0	1 15	2 58
31	Ave. K. W. During Run	13 9	13 1	19 2	11 9	13 1	24 7	43 5	21 9	61 2	148 5	37 0
32	Cost Per K. W. Hr.	5 15	5 85	4 25	6 00	6 15	3 86	3 13	5 09	3 06	1 85	4 62

EXPLANATION OF ITEMS ON TABLE III

All costs are given in dollars except those for indicated horse power hours, brake horse power hours, and kilowatt hours which are given in cents.

Items 4, 5, 6 and 7 give the number and ratings of only those engines and boilers actually operated in the test runs. Any reserve units are mentioned in the notes of equipment. Items 8, 9 and 10 include the cost of any reserve machinery and the costs per horse power are obtained by dividing the total costs by the rated horse power of the engines actually operated.

Item 11 gives the fixed charges per indicated horse power year and includes interest, depreciation, repairs, insurance, and taxes. Expressed as a percentage of the total initial cost, this item varies from 11.3% in the case of plant No. 8 to 18% in the case of plant No. 4.

Item 21, Boiler and Grate Efficiency, gives the per cent of heat in the coal actually absorbed by the water in the boiler.

Item 22, Efficiency of Conversion, is the ratio of the energy delivered at the switch board to that given the engine piston by the steam.

Item 23, Efficiency of Plant, is the ratio of the energy delivered at the switch board to that in the coal as fired.

Item 24 is the load factor or ratio between the average load and the peak load when both terms of the ratio refer only to the time during which the plant was operated.

Item 25 is the load factor or ratio between the average load and the rated capacity of the plant when both terms refer only to the time during which the plant was operated.

Item 26 is the load factor or ratio between the average load and the rated capacity of plant when the first term of the ratio refers to the time operated and the second term refers to 24 hours operation per day.

All three kinds of load factors are figured from the indicated horse power of engines and are based upon 365 days operation per year.

Item 27 is the average indicated horse power developed as figured from the indicator cards taken during the test.

Item 29, Average Brake H. P. is figured from the average indicated horse power by assuming approximately equal losses of conversion in engine and generator.

Item 31, Average Kilowatts, was figured from the switch board instrument readings.

In the case of the turbo-generator in plant No. 10, the efficiency of conversion was figured at about 70% for the test load. The rating of 750 Indicated H. P. was figured from the 500 K. W.

rating by assuming an efficiency of conversion of about 90% at full load. The load factors for this same plant were figured from the kilowatts.

EQUIPMENT OF PLANTS TESTED

Plant No. 1

1 Simple Engine, 80 H. P.
2 Boilers, 100 H. P. each.
Feed water heater.
No reserve units.

Plant No. 2

1 High Speed Engine, Simple, 100 H. P.
1 Boiler, 100 H. P.
Feed water heater.
1 Reserve Boiler, 100 H. P.

Plant No. 3

1 Simple Engine, 70 H. P.
1 Simple Engine, 45 H. P.
2 Boilers, 70 H. P. each.
No reserve units.

Plant No. 4

1 Corliss Engine, 100 H. P. run 5 hrs. per day.
1 Corliss Engine, 20 H. P. run 13 hrs. per day.
1 Boiler, 60 H. P.
1 Boiler, 20 H. P.
Feed water heater.
No reserve Units.

Plant No. 5

1 Compound Engine, 150 H. P., run from 3:00 A. M. to 12:00 midnight, and from 5:00 A. M. to 10:00 A. M., making 14 hours of service per day for engine.
1 Boiler, 200 H. P., fire kept banked while engine was not running.
1 Reserve Engine, 75 H. P.

Storage Battery used as auxiliary to provide 24-hour service.

With the same boiler efficiency a lower priced steam coal would have reduced the K. W. Hr. cost from 6.15 cents to 5.2 cents.

Plant No. 6

1 Simple Corliss Engine, 165 H. P.
2 Boilers, 100 H. P. each.
Feed water heater.
No Reserve Units.

Plant No. 7

1 Corliss Engine, 120 H. P.
1 Corliss Engine, 80 H. P.
1 Boiler, 120 H. P.
1 Boiler, 80 H. P.
No Reserve Units.

Plant No. 8

1 Corliss Engine, 350 H. P.
1 Boiler, 150 H. P.
Feed water heater.
1 Reserve Engine, 75 H. P.
1 Reserve Boiler, 125 H. P.

Plant No. 9

1 Tandem Compound Engine, 225 H. P.
1 Simple Engine, 150 H. P.
2 Boilers, 200 H. P. each.
Feed water heater.
1 Reserve Engine, Simple, 120 H. P.

Plant No. 10

1 Curtis Vertical Condensing Steam Turbine, 500 K. W.
2 Boilers, 500 H. P. each.
No Reserve Units.

The indicated horse power of the steam turbine is used as 750 on the data sheet. This figure is obtained by assuming a conversion efficiency of about 90% at full load.

COMPARISON OF DATA ON TABLES I AND III

The results of actual tests are given to show how the estimated efficiencies and costs check with those found in actual practice. A very direct comparison is difficult to make because of the irregularities in cost of plants, hours of operation, load factors and types of equipment. Also most of the tests were made on plants of small capacities.

The point of load factors should receive special attention. There is some disagreement among engineers as to the correct definition of load factor. To avoid misunderstanding on this point, load factors based upon different standards are given together with a definition of each.

On Table I (estimated costs) the different percentages of load factor are based upon a peak load which is assumed to equal the full rated capacity of plant. On Table III (actual costs) the peak load was found to be below the rated capacity in all cases.

If the load factor based upon the rated capacity in the actual tests is used as a basis for comparison, the cost per unit of energy is found to be considerably below the estimated costs. But if the factor based upon the actual peak load is used, the actual check quite closely with the estimated costs. On Table I the operating expenses are put at a price which assumes the ability to produce a peak load of rated capacity at any time. On Table III the operating costs are at a price which insures the ability of the plant to produce not rated load but the actual peak load at any time. From this then, it appears that the most logical load factor to use is the one based on the actual peak load of the day. The following comparisons are made upon this principle.

The estimated costs assume two methods of operation as regards hours operated per year. The first assumes 10 hours per day, 310 days per year. The second assumes 24 hours per day, 365 days per year. The first is of value in getting at the cost of power for factories operating only 10 hours per day and 6 days per week. The second is of value in getting at the cost of all classes of power supplied every hour of the year. Most electric central stations operate every day of the year, although many run less than 24 hours per day. Referring to Table III it will be noticed that for the plants as tested the average number of hours operated per day is 18.

The following is a comparison between the averages of the actual tests and the figures of the nearest corresponding estimated case.

	Actual	Estimated
Hours per year	6570	8760
I. H. P. of Plant	230.5	200
Total Cost per I. H. P.	$ 75.50	91.12
Fixed Charges per I. H. P. Yr.	$ 10.35	12.75
Operating Cost per I. H. P. Yr.	$ 28.50	66.32
Total Cost per I. H. P. Yr.	$ 38.85	79.07
Cost of Coal per 2,000 lbs.	$ 2.36	2.00
B. T. U. per Lb. Moist Coal	10,150	9,000
Load Factor	.489	.50
Average Brake H. P. Developed	61.8	85.0
Cost per Brake H. P. Hr., Cents	2.58	2.13
Average K. W. Developed	37.	47.5
Cost per Kilowatt Hr., Cents	4.62	4.08

The greatest difference in the above comparison is with the operating expenses per rated horse power year. It is much lower in the "actual" column than in the "estimated" column because in the first case the plant is so operated as to produce a maximum load of only about two-thirds the rated load, while in the second case the plant is so operated as to produce the full rated load at any time. Also in the first column, the time operated is but 75% of that in the second.

The costs per unit of energy are slightly higher in the "actual" column than in the "estimated" column, but the average hours operated is only 75% of the time operated in the "estimated" column, which would naturally tend to make an even greater difference than that shown.

By a general comparison of all figures, the estimated costs seem to be higher than those figured from the actual tests in Iowa power plants: this is especially true as the load factor decreases. It is possible, however, that in the case of the tests certain operating expenses were omitted, such as management and bookkeeping.

Following is the relationship between some additional corresponding items on Tables I and III.

Table I: Steam consumption ranges from 13 to 30 lbs. per I. H. P. Hr.
Table III: Same ranges from 23 to 46.4.

" I: Boiler pressure ranges from 100 to 150 pounds per square inch by gauge.
" III: Same ranges from 57 to 125.

" I: Efficiency of boiler and grate ranges from 55 to 60%.
" III: Same ranges from 44 to 65%.

" I: Water evaporated per pound moist coal ranges from 5.3 to 6.8 pounds.
" III: Same ranges from 4.1 to 7.87.

" I: Pounds coal per indicated H. P. Hr. ranges from 1.92 to 7.0.
" III: Same ranges from 4.2 to 9.9.

" I: Efficiency of conversion ranges from 49 to 81%.
" III: Same ranges from 50 to 81%.

" I: Cost of coal per million B. T. U. ranges from 11.1 to 13.6 cents.
" III: Same ranges from 8.1 to 15.3 cents.

NOTE: In all the above comparisons, except efficiency of conversion, the figures are taken from Table I at 100% load factor, and from Table III at whatever load factor occurred in each case. Efficiency of conversion was taken from the extreme limits in both cases.

BULLETINS OF THE ENGINEERING EXPERIMENT STATION

*No. 1. The Iowa State College Sewage Disposal Plant Investigations.
*No. 2. Bacteriological Investigations of the Iowa State College Sewage.
*No. 3. Data of Iowa Sewage and Sewage Disposal.
*No. 4. Bacteriological Investigations of the Iowa State College Sewage Disposal Plant.
*No. 5. The Chemical Composition of the Sewage of the Iowa State College Sewage Disposal Plant.
*No. 6. Tests of Iowa Common Brick.
*No. 7. Sewage Disposal in Iowa.
*No. 8. Tests of Dry Press Brick Used in Iowa.
*No. 9. Notes on Steam Generation with Iowa Coal.
*No. 10. Dredging by the Hydraulic Method.
*No. 11. An investigation of Some Iowa Sewage Disposal Systems.
*Vol. II. No. 6. The Good Roads Problem in Iowa.
Vol. III. No. 1. Tests of Cement.
Vol. III. No. 2. State Railroad Taxation.
*Vol. III. No. 3. Steam Generation with Iowa Coals.
Vol. III. No. 4. Incandescent Lamp Testing.
*Vol. III. No. 5. Steam Pipe Covering Tests.
*Vol. III. No. 6. The Assessment of Drainage Districts.
Vol. IV. No. 1. Tests of Iowa Limes.
Vol. IV. No. 2. Holding Power of Nails in Single Shear.
Vol. IV. No. 3. Miracle Contest Papers for 1908.
Vol. IV. No. 4. Miracle Prize Papers for 1909.
Vol. IV. No. 5. Sanitary Examination of Water Supplies.
Vol. IV. No. 6. Sewage Disposal Plants for Private Houses.
Bulletin No. 25. Electric Power on the Farm.
Bulletin No. 26. The Production of Excessive Hydrogen Sulfid in Sewage Disposal Plants and Consequent Disintegration of the Concrete.
Bulletin No. 27. A study of Iowa Population as Related to Industrial Conditions.
Bulletin No. 28. History of Road Legislation in Iowa.
Bulletin No. 29. Costs of Producing Power in Iowa with Iowa Coals.

* Out of Print.

5